ADDRESS

Delivered by the President, Mr. W. H. M. Christie, on presenting the Gold Medal of the Society to M. M. Lœwy.

It is now my pleasing duty to lay before you the grounds on which the Council have awarded the Gold Medal to M. Maurice Lœwy for his invention of the Equatorial coudé, of a new method of determining the constant of aberration, and for his other astronomical researches.

On examining the series of memoirs in which M. Lœwy has set forth his new methods of astronomical research, we are at once impressed by the originality of conception which characterises all his ideas, and by the thoroughness with which he has worked out the details necessary for the practical application of his new methods of observation. Observational astronomy has for many years past proceeded on such well-defined lines, that we have not unnaturally come to look rather to improvements of detail than to the introduction of new instruments for the advancement of our knowledge. It is, therefore, a matter of great satisfaction to find that M. Lœwy has placed at our disposal various methods of observation based on entirely new principles, and calculated to give astronomers improved and quite independent means of attacking several of the most important problems in our science.

The first of these new instruments with which I will deal is the Equatorial coudé.

It was in the year 1871 that M. Lœwy proposed his new form of equatorial, to which the name of "Equatorial coudé" has been given, and M. Delaunay, then director of the Paris Observatory, was so struck with the value of the principle, that he arranged for the construction of an instrument on this plan. M. Delaunay's death, however, interrupted the work, and the first Equatorial coudé, having an object-glass of $0^{m}.27$, or about $10\frac{5}{8}$ inches aperture, was not completed till the year 1882. The success of this instrument was so marked that its value could not fail to be recognised, and it was not long before the construction of several larger equatorials on the same principle was commenced. At the present time six Equatorial coudés have been completed, and four of these are already mounted and in

regular use at the observatories of Paris, Lyons, Besançon and Algiers. The other two are intended for the observatories of Paris and Vienna.

In principle the Equatorial coudé may be described as an adaptation of the form of transit instrument with axial view to the requirements of an equatorial, by the addition of a plane mirror, inclined at 45°, outside the object-glass, this mirror being capable of rotation about the axis of the telescope, so as to reflect into the latter the rays from any object in a perpendicular plane. The axis of the instrument is mounted as a polar axis between two piers, the telescope being broken at a right angle near the lower pivot, so that the rays from the object-glass are reflected by an internal mirror up the polar axis to the hollow upper pivot, where the image is formed. The rotation of the outer mirror thus brings into the field the image of any object in the hour-circle perpendicular to the object-end of the telescope, and by the rotation of the polar axis, as in an ordinary equatorial, the telescope is directed to any hour-angle. The declination-axis in the Equatorial coudé is the axis of the object end of the telescope about which the outer mirror turns, and the declination-circle placed at the eye-end, in the same plane with the hour-circle, is connected with the axis of the outer mirror by gearing, so that the observer at the stationary eyepiece has both the hour and declination circles immediately under his eye. He can thus direct the instrument to any object without moving from his chair, and his observations are made under the most favourable conditions for his own comfort, similar to those under which the microscope is used by the student of natural history. The observing room, which may be artificially warmed, is quite separated from the object-glass, and other external parts of the instrument. These latter are protected from the weather by a suitable hut, which can be rolled away on rails before observing, so that the optical parts of the equatorial are in the open air under the best conditions for establishing an equilibrium of temperature.

The importance of obtaining the favourable conditions for observation secured by M Lœwy's Equatorial coudé has long been recognised, and various attempts have been made to enable the observer to command any part of the sky without changing his position. In 1858 Dr. Steinheil proposed* a new method of mounting a reflector, so that the axis of the concave mirror formed the polar axis, the rays from a star being reflected down the axis to the concave mirror by a plane mirror, which could be rotated about a declination axis and a polar axis. The observer looked down the polar axis through a hole in the plane mirror, but with this arrangement he could not observe stars much north of the equator unless the plane mirror were made very large, and the range of the equatorial was thus very restricted. A more ex-

* *Astron. Nachrichten*, No. 1138, *Monthly Notices*, vol. xix. p 56.

tended range might be obtained by interchanging the concave and plane mirrors, so that the observer would look up in the direction of the pole; but the concave mirror and its support would block out the view of the region near the pole, and of all the sky below the pole. Sir H. Grubb has applied the same principle to the construction of a siderostatic refractor.

As compared with Dr. Steinheil's form the Equatorial coudé possesses the great advantage of commanding every part of the sky, the arm of the telescope below the elbow being made long enough to project beyond the sides of the observing room when viewing objects near the meridian.

The siderostat of Foucault, though useful for many purposes, is open to the same objection as Dr. Steinheil's, of not permitting of a view of every part of the sky; and there is the further difficulty that the apparent direction of the diurnal motion is continually changing. In the Equatorial coudé this direction changes with the declination, but M. Lœwy has now arranged that the micrometer is turned with the declination circle, and is thus always set to the zero of position angle.

The success obtained by M. Lœwy in the construction of the Equatorial coudé is due to the following circumstances:—

1. The absence of flexure in the mirrors, which are made much thicker than usual.
2. The more perfect achromatism secured by the greater focal length which this form of mounting allows of.

The first condition was established by careful experiment, which showed that in order to avoid deformation by flexure the thickness of a mirror should be between $\frac{1}{5}$ and $\frac{1}{6}$ of the diameter instead of $\frac{1}{9}$ or $\frac{1}{10}$ as had been usual hitherto.

As regards achromatism M. Lœwy urges that, in order to be able to see better with a larger object-glass, the achromatism must be made more perfect, and that, therefore, the ratio of focal length to aperture must increase with the aperture in order to diminish the effect of the secondary spectrum.

Notwithstanding the two reflections, the definition obtained with the Equatorial coudé appears to be very good, the components of ω *Leonis*, distant only $0''.5$, having been separated with the Paris instrument which has an object-glass of $0^{m}.27$, or about $10\frac{5}{8}$ inches. With one of the new instruments of $0^{m}.31$, or $12\frac{1}{4}$ inches aperture, M. Trépied at Algiers easily divided γ^2 *Andromedæ*. The loss of light by the two reflections from silvered mirrors is computed by M. Lœwy at only 12 per cent. and it would seem that it is at any rate very small, as successful observations of a minor planet of 13·5 magnitude were obtained with the Paris instrument as well as of very faint nebulæ and comets. The comet 1885 *d* (Fabry) was discovered with this instrument.

One of the objects which M. Lœwy had in view in planning

his Equatorial coudé was to obtain greater stability than is attainable with ordinary equatorials, and to make the measurement of large angular distances possible. The form of mounting of the Equatorial coudé seems peculiarly adapted to give great stability, provided the fixity of the mirrors in their cells can be secured, and this is a condition to which M. Lœwy has given special attention. Each mirror rests in its cell on thick felt or flannel, and is held by three clips, which are just brought into contact with it when in the horizontal position, as tested by the disappearance of the least trace of light between the clip and its reflected image. This adjustment being made for the horizontal position, in which the weight of the mirror has its full effect, perfect contact between the mirror and its clips will be maintained in all positions.

M. Lœwy, in conjunction with M. P. Puiseux, has investigated very completely the theory of the instrumental adjustments of the Equatorial coudé, including the effect of flexure of the polar axis and of the telescope arm, and has shown the relation of his formulæ to those for ordinary equatorials. He arrives at the two following conditions of optical adjustment as sufficient for astronomical purposes:—

1. The axis of the telescope arm should be perpendicular to the polar axis.
2. The interior mirror should reflect to the centre of the field a ray entering the telescope along the axis of the arm, supposed to be perpendicular to the polar axis.

The discussion of the instrumental errors of the Paris instrument, partly by astronomical observations, and partly by means of a collimator attached to the mounting of the exterior mirror, shows a very satisfactory accordance in the determinations on different days, and in the result the instrumental errors were found to be very small, the largest amounting only to 23″. The coefficients of flexure are, however, rather larger quantities, being 91″ and 53″ for the polar axis and telescope arm respectively, as found by means of the collimator. It may be expected that in the new instruments the effects of flexure would be very much less, as important improvements have been made in their mechanical construction.

It is not a little remarkable that the first instrument made on this new principle should have given such excellent results, both optically and mechanically, and its success is evidence of the thoroughness with which M. Lœwy has worked out his idea, and of the skill with which MM. Henry and M. Gauthier have respectively carried out the optical and mechanical portions of the instrument.

I now pass on to M. Lœwy's new method of determining the constant of aberration. It is hardly necessary to insist on the importance of this constant, not only for obtaining the true positions of the stars, but, in a higher degree, for the determina-

tion of the solar parallax by means of the velocity of light. It must be admitted that the nine independent determinations of the constant of aberration made at Pulkowa with three different instruments show a satisfactory accordance, but in the opinion of M. Nyrén, who has published the latest researches on the subject, none of these can be asserted to be free from systematic error. M. Nyrén's definitive value is $20''\cdot492$, exceeding by $0''\cdot047$ W. Struve's original value, which has hitherto been generally used by astronomers. Under these circumstances M. Lœwy's method, which is based on differential measures with an equatorial, constitutes a new departure of great value in astronomy of precision, and its value is enhanced by the circumstance that it is also applicable to the determination of the constant and law of refraction.

The principle of M. Lœwy's method is the measurement of the angular distance between two stars by means of a double mirror, formed by silvering two faces of a large prism of glass, and placed in front of the object-glass of an equatorial. The double mirror is capable of rotation about the axis of the telescope, so that by reflection from the two silvered surfaces the images of two stars in different parts of the sky may be brought into the field side by side, and the distance between them measured in the direction of the common plane of reflection. In his memoir on the determination of refraction by the new method, M. Lœwy proves that the projection of the distance between the two images on the trace of the common plane of reflection is independent of the rotation of the equatorial, of any movements of the double mirror, and of the displacement of the images by the diurnal motion, when the observation is not made rigorously in the plane of reflection.

M. Lœwy's exposition of his method of determining the constant of aberration is contained in a series of communications made to the French Académie des Sciences and published in the *Comptes Rendus*, vols. civ. and cv. In giving an account of this investigation, I will proceed at once to the general method for determining aberration, which M. Lœwy discusses after treating some special cases.

The determination of aberration requires the measurement of the distance between a pair of stars at successive epochs when the effect of aberration on the angular distance is reversed. The observations are made when the two stars have the same altitude, so that the effect of refraction is a minimum, and the comparison of the two measures gives a multiple of the constant of aberration, which is independent of all instrumental errors and also of precession and nutation, as the distance between two stars is unaffected by any movements of the earth's axis or of the ecliptic. There is the further advantage in the new method, that the effect of aberration as measured is much greater than in the ordinary methods of observation.

But the result might be affected by change of refraction or

by alteration in the angles of the double mirror resulting from thermal expansion between the two epochs of observation, and M. Lœwy has therefore imagined a general method of observation which eliminates any possible effects of the kind, as well as methods applicable to special cases which determine any changes due to refraction or expansion of the mirror.

The essence of the general method is that two pairs of stars are observed, the four stars being selected so that at the time of observation they are all simultaneously at the same altitude and that the effects of aberration on the two arcs connecting the stars of each pair are large and of opposite sign. Thus the two arcs formed respectively by the two pairs of stars are compared simultaneously both at the first and at the second epochs.

The first point for investigation is the effect of aberration on the angular distance between a given pair of stars. From the geometrical conditions M. Lœwy arrives readily at the result that the effect is proportional to the cosine of the angle between the median* of the arc and the direction of the Earth's motion.

Calling Δ the angular distance between two stars,
p the angle between the median of the arc joining them and the direction of the Earth's motion,
and k the coefficient of aberration,

the effect of aberration is given by the formula

$$d\Delta = 2k \sin\frac{\Delta}{2} \cos p.$$

It readily follows from this that the effect of aberration on the difference of the two arcs connecting two pairs of stars will be greatest when the two medians are on the same vertical circle on opposite sides of the zenith. Under these circumstances, the effect of aberration on the difference of the two arcs is equal to

$$4k \sin\frac{\Delta}{2} \sin\frac{\Delta'}{2} \cos L,$$

Δ' being the angular distance between the two medians, and L the angle between the direction of the Earth's motion and the line of intersection of the vertical plane through the medians with the horizon. Thus the effect is proportional to the cosine of this angle, and the greatest effect will be obtained when the vertical plane of the medians, the ecliptic and the horizon intersect in the same line, and the observations are made at the two epochs six months apart when the direction of the Earth's motion coincides with this line, L having the values 0° and 180° at the two epochs respectively. In that case the effect of aberration on the difference of the two arcs has opposite signs at the two

* The median is the line bisecting the angle between the directions of the two stars.

epochs, and the comparison of the two sets of measures of the two arcs gives

$$E = 8k \sin\frac{\Delta}{2} \sin\frac{\Delta'}{2},$$

where E is the difference of the two measures of difference of arcs at the first and second epochs respectively.

The next point for consideration is the choice of the angle for the double mirror, the angular distance (Δ) between the two stars in each pair being necessarily twice this angle. Obviously the altitude at which the observation of the four stars is made diminishes as Δ and Δ' increase, and M. Lœwy shows that the maximum effect at any given altitude is obtained by making $\Delta' = \Delta$, or the angular distance between the medians the same as that between the two stars in each pair. He then gives the following table of the altitude h and of the effect of aberration $\frac{E}{k}$ corresponding to the several values of the angle of the double mirror a :—

a	30°	35°	40°	45°	50°	55°	60°
h	48° 35′	42° 9′	35° 58′	30° 0′	24° 24′	19° 12′	14° 29′
$\frac{E}{k}$	2·0	2·6	3·3	4·0	4·7	5·4	6·0

M. Lœwy concludes that the angle of the double mirror should not exceed 50°, and he considers that on the whole it would be well to make it 45°, so that the altitude of the stars would be 30°, and the angular distance for each pair 90°. Under these conditions observations made at two epochs six months apart would give as the quantity measured four times the constant of aberration, while the ordinary methods of observation only give at the maximum a measure of twice the constant. But in order to avoid daylight observations M. Lœwy thinks it would be advisable to be satisfied with a slightly smaller coefficient of k (the constant of aberration), say three instead of four, which would reduce the interval between the two epochs to about ninety-eight days, and by combining the observations in the first five weeks with those in the last five, a series of equations would be obtained in which the coefficient of k would vary from three to one, the mean value being about two. All the observations could then be made in the night hours.

Besides the general method of observation just described, M. Lœwy has, as already mentioned, devised two methods applicable to special cases which are well suited to give independent determinations of the constant of aberration.

The first method consists in the observation of two pairs of stars, of which one pair gives at the end of two or three months the measure of twice the constant of aberration, and the other, completely unaffected by aberration, exhibits the effect of tem-

perature on the double mirror. The first pair of stars should be in the neighbourhood of the ecliptic; the second pair is, as will be seen from geometrical considerations, to be chosen so that the latitudes of the two stars are the same, and that their longitudes differ by 180°, in order that the arc joining them may be unaffected by aberration.

This method is, however, not applicable at observatories within 20° of the equator, and on this account, as well as to give another independent determination of the constant of aberration, M. Lœwy proposes a second method according to which the angular distance of a single pair of stars near the ecliptic is to be observed for a period of three months or longer, the measures in the first and last twenty-five days of the period being used to determine the aberration, and those in the intermediate forty days to deduce the effect of temperature on the double mirror.

The question of the adjustment of the double mirror remains to be mentioned. This must be mounted so as to turn about the optical axis, and this axis should coincide nearly with the axis of figure. The effects of any movements of the double mirror will then be as follow:—

1. In turning round the axis of figure the two images are displaced in opposite directions, but perpendicularly to the trace of the common plane of reflection.
2. In turning round an axis in this plane and perpendicular to the axis of figure the two images move in the same direction perpendicularly to the trace of the plane of reflection.
3. If the double mirror turns about an axis perpendicular to the plane of reflection, the two images move along the trace without changing their relative distance.

Reference has already been made to the applicability of M. Lœwy's new method to the determination of refraction at various altitudes. This was, in fact, the immediate object which M. Lœwy had in view when he devised the method, and his investigation of the conditions of the problem was communicated to the French Académie des Sciences early in 1886, the year before he published his memoir on aberration.

In his series of papers on the determination of refraction published in the *Comptes Rendus*, vol. cii., M. Lœwy first gives a method for determining the constant of refraction, the law according to which refraction varies with the altitude being known. A pair of stars is observed when refraction has its maximum effect on their angular distance, and again when the effect of refraction is a minimum. For the maximum effect one of the stars must be on the horizon, and the other in the same vertical circle with it, while for the minimum both stars must be at the same altitude. M. Lœwy then finds that the greatest variation of refraction will be obtained with an angle of 30° for the double mirror, but as with this there would be (for

the latitude of Paris) a minimum interval of $6^h\ 35^m$ between the two epochs of observation, he prefers to take an angle of 45° for the double mirror, sacrificing only 15″ in the effect of refraction, while reducing the interval between the observations to $4^h\ 44^m$. This is the minimum value of the interval found by selecting the pair of stars so that their common zenith distance at the second epoch is equal to the angle of the double mirror, or half the angular distance between the two stars.

The geometrical conditions thus found by M. Lœwy to give the maximum effect in the minimum interval of time between the observations may be somewhat modified in practice, provided the angular distance between the stars does not differ by more than a few minutes from twice the angle of the double mirror. M. Lœwy has thus been able to find some twenty pairs of bright stars suitable for the determination of refraction by this method. In its practical form the method consists in the measurement of the angular distance between a pair of stars 90° apart when one of the stars is near the horizon and the other near the zenith, and again when both the stars are at about the same altitude. It is not necessary that at the former epoch the low star should be very near the horizon, for, as M. Lœwy points out, observations may be advantageously continued till the altitude is nearly 20°, and thus the constant of refraction may be determined from observations which are practically unaffected by any uncertainty in the law of refraction.

It will readily be understood that the observation of the low star may be made either when it is rising or when it is setting. In the latter case the observation of the stars at equal altitude would precede that for which one of the stars is setting. By combining the observations of two pairs of stars chosen so that the first pair is rising when the effect of refraction on the second is a minimum, and that the first pair is at the minimum when the second pair is setting, the influence of any change in the angle of the double mirror will be eliminated by taking the mean of the two determinations, while the difference of these will give four times the change of angle in the interval, thus affording a precise determination of any such change, if it exists.

Various other methods are proposed by M. Lœwy for determining the refraction at any altitude without assuming its law of variation. These methods, however, appear to involve practical difficulties, as they either assume the absence of irregular variations in the refraction at an altitude of 10°, or require the construction of several double mirrors with different angles. They may be considered as supplementing the first method; and they are of interest as giving a direct measure of refraction independently of any theory.

The practical determination of the constants of aberration and refraction by the new method is being carried out by M. Lœwy and M. P. Puiseux with the Equatorial coudé of the Paris

Observatory, and the series of observations made during the past twelve months confirms in the most satisfactory manner the theoretical conclusions. M. Lœwy finds that the variations of the distances are really free from systematic errors, and he considers that the constant of refraction will be more accurately determined from a few nights' observations with his new method than from years of meridian observations.

In conclusion I can only allude in the briefest terms to the other important researches for which astronomers are indebted to M. Lœwy. The following is a summary of the other new methods of instrumental research which M. Lœwy has devised in the last few years :—

1. A method for determining the flexure of transit-circles at various zenith distances by means of an optical apparatus inserted in the central cube. This has been used to find the flexure of two transit-circles at the Paris Observatory, the absolute values of the flexure for the two ends of the telescope and for the axis being independently determined.

2. A method for obtaining the latitude without making use of the declinations of fundamental stars.

3. A general method for determining right ascensions without relying on assumed right ascensions of polar stars.

4. A method for finding on each night the absolute declinations of stars without the necessity for observations of polar stars at upper and lower transit.

5. Methods for determining directly the two co-ordinates of polar stars without a previous investigation of the instrumental errors.

All these methods except the first are based on the observation of close circumpolar stars in R.A. and N.P.D. out of the meridian at various points of the circles described by them. Conjugate observations either of a single star or of a pair of stars having the same N.P.D. are made with a transit-circle, having a field of view of 2°, at equal intervals (about two hours) before and after meridian passage or before and after passage over the hour-circle of 6^h east or west. The special methods of observation are developed in a series of communications to the French Académie des Sciences made in the years 1883 and 1885, and during the last two years M. Renan has applied these new methods to a determination of the latitude of the Paris Observatory based on 80 very accurate results.

The account which I have given of M. Lœwy's inventions and researches is necessarily very imperfect, and I have had to pass over many points of interest in the application of his methods. But I trust that the summary I have made will at any rate suffice to show the very high importance of M. Lœwy's labours, and that they fully deserve the recognition which is to-

day given to them, whether we have regard to the originality of the methods or to the value of the results which are to be obtained from them.

The President then, delivering the Medal to the Foreign Secretary, addressed him in the following terms:—

Dr. Huggins,—In transmitting this medal to M. Lœwy I would ask you to assure him of our very high appreciation of the services which he has rendered to Astronomy by the invention of his Equatorial coudé and of his new methods for determining important astronomical elements, and to express our hope that his life and strength may long be spared to enable him to continue the successful application of the instrumental means he has devised for the advancement of our science. We deeply regret that we are deprived of his presence to-day, through the effects of a serious accident, but trust that he will ere long be completely restored in health and vigour.